The Effect of Removing the Force Feedback during the Quiet Stance

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Abstract. The human postural control system is complex and it combines information from different sources. The most important information comes from vestibular, visual and proprioceptive senses. We studied the effects of removing the visual and proprioceptive information simultaneously. The force feedback from the ground was removed with vibrators attached on the musculus soleus of both calves. By using features of force platform signals, when the vibrators were on, the lengths of the swaying paths were four times the lengths when the vibrators were off. Our results show that it is possible to separate the effects of the visual and proprioceptive senses from that of vestibular sense, which is very useful for investigations of balance problems in otoneurology. This supports our future aim to classify between healthy subjects and different otoneurological patients with signal analysis and pattern recognition methods to be used for force platform signals.

Keywords. balance, biomedical signal analysis, force platform signals

1. Introduction

The majority of people do not have to pay attention to their postural stability during normal daily activities. However, there are plenty of people who have problems in maintaining their upright stance. The impaired balance may originate from certain diseases, for instance Menière’s disease [1, 2] and vertigo [3, 4]. Also, different solvents [5] and noise [6] in working places can affect human postural control system. However, the most common factor leading to difficulties in maintaining balance is aging [7–9].

Numerous elderly people who have problems with their balance suffer from the fear of falling. This can easily lead to the situation where an elderly person does not move at all, weakening his/her physical condition dramatically. This can further produce social isolation and the reduction of the quality of life. To prevent such situations, the early detection of balance deficits is important. After the nature of a balance problem is known, suitable rehabilitation methods can be suggested.

The human postural control system is very complex. It integrates information from vision, proprioceptors in muscles and vestibular system in the inner ear. Although a

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person’s balance is good when all the three information sources are in use, the effect can be surprising when one or more of the information sources are blocked. For instance, the basic Romberg’s test measures whether a subject is swaying more with the eyes closed than with the eyes open. This test can reveal that a person cannot stand steadily without visual feedback from the environment. In this case a subject might benefit from balance training where there is not visual information present.

The purpose of this work was to examine the use of force platform signals in order to remove the visual and proprioceptive information at the same time and, thus, to “subtract” their effects from the balance of a subject, but to keep that of the vestibular sense. Such a condition is very interesting for otoneurology to investigate the possible dysfunction of a subject’s vestibular sense.

2. Materials and Methods

The material was collected from 82 medical students aged 23±2 years (66 females, 16 males). All subjects were healthy. They had no balance problems that could have affected the measurements. The tests were conducted in the Tampere University Hospital with a force platform depicted in the left side of Figure 1. These young, healthy subjects of a homogeneous age group were taken to form an average “prototype” of young adults, which can be utilized for comparisons to other age groups and particularly patients in our future studies.

The force platform contains three force sensors under its brink. When a subject is standing on the force platform, the resultant force location under the subject’s feet is recorded at the frequency of 50 Hz. The resulting force location is often called the centre point of pressure (COP). A result from the force platform is a two-dimensional time series, which contains the COP locations in anterior-posterior y[t] and medio-lateral x[t] directions at every sampling instance t. This result is called a stabilogram. There is an example from a random subject in the right side of Figure 1.

We measured three stabilogram signals from each subject. Two 25 s measurements with the Romberg’s test, in which a relaxed subject stood on the force platform first with the eyes open and then with the eyes closed. The third stabilogram was a 38 s measurement from our own vibration test. Vibrators are a common tool used to block the proprioceptive sense. For instance, see [10].

Figure 1. Force platform which measures COP and an example stabilogram
Before a vibration test, two vibrators were attached at the top of the musculus soleus of both calves of a subject. To perform a test a subject was instructed to stand still with the hands on the breast and the eyes closed. After 10 s of quiet stance the vibrators started and ran for 28 s at the frequency of 13 Hz. During a test there was an assistant present to prevent possible falls.

To suppress the effect of vibrators, the measured signals were lowpass filtered with a finite impulse response (FIR) filter designed with Matlab. Its passband ended at 10 Hz, and its stopband started at 11 Hz. The attenuation in the stopband was 80 dB, and the ripple in the passband was 1 dB. Also, the signals measured without vibrators were similarly filtered.

After filtering the vibration test signals were divided into two parts. The former part contained 7 s of swaying data with eyes closed and the vibrators turned off. The time interval of this part was from 2 to 9 s from the beginning of a test. The latter part contained 7 s of the data with eyes closed and the vibrators turned on. The time interval of this part was from 25 to 32 s from the beginning of a test. The latter time interval was selected because the swaying velocity of a subject is settled to a near constant level after the vibrators start at the time instant of 25 s. This can be seen in Figure 2.

For every subject we calculated a Romberg quotient \( R \) on the basis of measurements from the eyes open and the eyes closed measurements. The similar quotient \( Q \) was calculated on the basis of the two parts from vibration test measurements. We calculated the quotient \( Q \) as follows

\[
Q = \frac{\sum_{i=1}^{N} \sqrt{\Delta x_{VC}(t)^2 + \Delta y_{VC}(t)^2}}{\sum_{i=1}^{N} \sqrt{\Delta x_C(t)^2 + \Delta y_C(t)^2}},
\]

where the numerator contains the total length of the swaying path with the eyes closed and the vibrators turned off. In the denominator there is the total length of the swaying path with the eyes closed. In both cases \( \Delta \) means the time difference of respective \( x \) and \( y \) signals. This quotient tells us the relative increase in the swaying when the proprioceptive force feedback from the platform is removed.

### 3. Results

The quotients from Romberg and vibration tests are presented in Figure 3. We notice that the relative increase in swaying is greater in the case of the vibration test among the majority of the subjects. The mean quotient in the Romberg test was 1.66±0.42, and the respective value in the case of the vibration test was 4.0±2.56. This shows that the proprioceptive feedback from environment is very important. Although all subjects were young adults, they all had difficulties to maintain balance during the vibration test. Especially, the transition phase when the vibrators started was challenging. Two subjects fell down, and their measurements were excluded from further calculations.

The effect of starting the vibrators is depicted in Figure 2, which contains the ensemble average velocity of all subjects. Two seconds were removed from the beginning of the velocity graph because of the filtering transient and the subjects
accustoming to the test procedure. Starting the vibrators led to the phenomenon that all subjects leaned backward in a very large extent. This yielded an increase of swaying velocity and caused two subjects to fall down. When a subject navigated this phase, he/she managed to stabilize the balance. However, the swaying velocity remained high.

![Figure 2. The ensemble average velocity graph from the vibration tests](image1)

To further analyze the results from the measurements we built a linear model that would predict a quotient $Q$ given quotient $R$. However, such attempt did not succeed. The correlation coefficient between $R$ and $Q$ was only $0.074$ and the $p$ value for accepting the null hypothesis was $0.5$. Against this background we had to make a conclusion that quotients $Q$ and $R$ are linearly uncorrelated. This useful observation reinforces our belief that the components of human postural control system are not correlated and complement each other.

![Figure 3. The average results of the Romberg and vibration tests of 80 subjects](image2)
4. Discussion and Conclusion

By applying force platform signals, we studied the effects of blocking the visual and proprioceptive information at the same time during quiet stance. Our results showed that this is technically possible to perform. For the first time, Q and R were used as pattern recognition features in this way. An important observation was their uncorrelatedness. These properties could be used with machine learning methods in our future research to separate patients from the healthy and possibly subjects between different age groups.

Although our subjects were young and healthy, they had difficulties to maintain their balance. When the human postural control system is a combination of visual, proprioceptive and vestibular systems, it seems to be possible to locate the nature of possible balance deficit of a patient by blocking one or two of these information channels at a time. Of course, the vestibular information must always be available. The vestibular organs and their dysfunction are important investigation targets in otoneurology. If a weak component of the human postural control system of a subject is found, specific rehabilitation methods can be suggested to a person suffering from balance disorders.

We applied our force platform signals to a homogeneous group of 82 young, healthy subjects to eliminate possible effects of diseases and age. In this way, we also built a suitable normal material to later extend our investigations to otoneurological patients and other age groups, i.e., children, middle-aged, elderly and oldest old people.

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References